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Development of a Stadiametric Ranging Device for the M203 Grenade Launcher

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ARI Field Unit at Fort Benning, Georgia
Training Research Laboratory

U. S. Army
Research Institute for the Behavioral and Social Sciences

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This research sought to improve performance on the M203 grenade launcher through the development of a simple, low-cost range estimation device using stadiametric principles. Experiment 1 established the baseline unaided range estimation capability of grenadiers who were newly weapon qualified. Experiment 2 was a pilot test of a prototype stadiametric ranging device that used hole sizes scaled to each of 10 man-sized targets located between 50 and 350m from the firer. On the basis of systematic perceptual errors associated with the original device, corrections to the hole sizes were calculated (Continued)

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and incorporated into a corrected device. Experiment 3 compared both ~~these~~ devices using experienced soldiers, who provided unaided eye range estimations as the baseline. Range estimates with the unaided eye were overestimations of ranges and those with the devices were underestimations. The magnitude of range estimation errors was smaller and showed less variability through use of the devices than with the unaided eye. Outbound targets yielded less range estimation error than inbound targets with the naked eye. In contrast, inbound targets yielded less estimation error than outbound targets for both ranging devices. The influence of the direction of target movement on range estimates is discussed in the context of known sources of error in stadiametric devices and design features of the prototype devices.

Research Report 1433

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FOREWORD

The Fort Benning Field Unit of the Army Research Institute has completed numerous experiments to improve performance on the M16A1 rifle and the M60 machine gun. These research programs have evaluated the operational effectiveness of these weapons, and when appropriate, offered design improvements to increase firer proficiency. The research reported here makes a contribution of a simple, low-cost, and easily incorporated ranging device for the M203 grenade launcher. Since range estimation is a slowly acquired, but easily lost, skill critical to grenadiers' performance, the solution for increased proficiency is best realized by a range estimation aid integral to the weapon. The design specifications of such a device are provided in this report, together with range estimation performance data collected during field tests. The effects of the direction of land-based target movements on range estimates also are discussed, as are systematic sources of error in stadiametric ranging devices.

EDGAR M. JOHNSON
Technical Director

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DEVELOPMENT OF A STADIAMETRIC RANGING DEVICE FOR THE M203 GRENADE LAUNCHER

EXECUTIVE SUMMARY

Requirement:

A major skill component for firing the M203 grenade launcher is making accurate range estimates to the target. After establishing the baseline performance of grenadiers in range estimation, this research sought to improve performance through development of a simple, low-cost ranging device using stadiametric principles. The ranging device incorporated design features to reduce known sources of stadiametric errors.

Procedure:

Experiment 1 established the baseline range estimation capability of newly weapon qualified grenadiers. Experiment 2 was a pilot test of the stadiametric ranging device using hole sizes scaled to each of 10 man-sized targets located between 50 and 350m from the firer. On the basis of systematic perceptual errors associated with the original device, corrections to the hole sizes were calculated and incorporated into a corrected device. Experiment 3 compared both these devices using experienced soldiers, who provided unaided eye range estimates as the baseline. Device range estimates were obtained by allowing the firer to adjust the target distance until the image "just fit" the hole corresponding to the range to be estimated. Distance estimates were interpreted in terms of range from the firer to the target, magnitude of errors from the actual range, and variability of observers' errors. The experimental design controlled for differences in the range estimation abilities of the observers, the effects of order of use of the devices, and the influence of environmental cues.

Findings:

1. Both trainees and experienced soldiers tend to overestimate distances with the naked eye, progressively making larger errors as distance increases.

2. With knowledge of what range values are to be estimated, soldiers can make reasonably accurate range estimates.

3. Both the original and corrected ranging devices provide underestimates of range between the observer and the target. Underestimates tend to become larger as range increases.

4. Beyond 175m the direction of target movement is an important source of land-based range estimation error. Outbound targets yield less range estimation error than inbound targets with the naked eye. In contrast, inbound targets yield less estimation error than outbound targets for both ranging devices.

5. The magnitude of range estimation errors is smaller (except beyond 300m) and shows less variability through use of the devices than with the unaided eye.

6. For a stadiametric ranging device of fixed aperture design, diffraction is a source of estimation error.

7. Although training in the use of the device was not investigated, the judgmental basis for fitting target image size to the comparison appears susceptible to training modification and improvement.

Utilization of Findings:

With minimum cost, the ranging device developed in this research could easily be substituted for the rarely used leaf sight on the M203 grenade launcher. For inexperienced grenadiers, or under conditions of unfamiliar terrain, use of the device could result in improved performance, especially for first rounds.

DEVELOPMENT OF A STADIAMETRIC RANGING DEVICE FOR THE M203 GRENADE LAUNCHER

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INTRODUCTION

The effectiveness of both direct and indirect fire weapons is in part dependent on the soldier accurately estimating the range between himself and the target or between two points observed from another position. A rifleman, knowledgeable of the trajectory of the M16 bullet, adjusts his point of aim on the basis of unaided eye estimates of the range to the target. On the other hand, firers of some weapons systems like the M72 Light Antitank Weapon or recoilless rifles have the benefit of stadiametric ranging aids. Indirect fire weapons (81mm and 107mm mortar systems) employ a forward observer to spot the rounds and report discrepancies between the strike of the round and the intended target. These forward observers use a stadiametric ranging aid built into binoculars to assist in their range estimates. Even with the advent of laser ranging devices and high power optics in tanks and fighting vehicles, the optical systems include ranging stadia for crew use.

The 40mm M203 grenade launcher is attached to the M16A1 rifle (see Figure 3) and includes two sights--the quadrant sight and the leaf sight. The quadrant sight mounts on the left side of the carrying handle of the rifle. The quadrant sight must be set to account for the distance between the firer and the target and is graduated in 25-m increments from 50 to 400 m. The leaf sight is located on top of the handguard and has a folding, open ladder design that permits rapid firing without sight manipulation. The leaf sight is graduated in 50-m increments from 50 to 250 m and numbered at 100 and 250 m. Neither sight is designed to facilitate decisions about the range between the firer and the target. Ranging must be accomplished without the benefit of any ranging aid, a requirement made more difficult by the small 5 m effective burst radius of most grenade rounds. The grenadier not only must estimate range for his first shot, but must do so very accurately to receive a first round hit. These tolerances appear well beyond the ability of newly trained grenadiers or soldiers who fire the M203 at infrequent intervals. Moreover, current Army policy has not emphasized known methods of unaided eye range estimation in a broad range of weapons and tactical training situations (Thompson, 1982).

Interest on the part of the U.S. Army Infantry School in improving the overall skill level of M203 grenadiers resulted in ARI-Fort Benning Field Unit scientists observing basic M203 marksmanship training at Fort Benning. While mechanical training on the weapon appeared adequate, the amount of time spent on range estimation seemed limited for the fine-tuned range estimation skill required by the weapon. Informal observations of trainee difficulties in making correct sighting adjustments led to two questions. The first was "How well can soldiers estimate range out to 350 m, the maximum effective range of the M203?" The second was "Can a simple ranging aid be developed for the M203 using stadiametric principles?"

The first question was intended to determine whether range estimation skill was sufficient to fire well-placed rounds. The second question had a number of implications. The first was whether the weapon system could accommodate another piece of equipment, a ranging aid. The second was that any ranging device design had to be inexpensive, since solutions like telescopic sights, though effective, could not be widely dedicated to grenade launcher use. The third was that errors in range estimation are known to occur in ranging devices using stadia lines. Giordano (1976) identified three major sources of stadia errors as (a) the thickness of the stadia lines which may introduce uncertainty of how to align the target image and the stadia lines, (b) movement or unsteadiness of the stadiametric system which appears to reduce the separation between the stadia and (c) movement and obscuration of parts of the target.

It was this final point of the error possibilities with stadia lines which suggested a different approach to employing stadiametric principles while at the same time offering the opportunity to improve M203 performance. The principles of stadiametric ranging aids are as follows. The judgment of range involves the comparison of the apparent size of the distant target with that of some standard which is located close to the observer. The standard is of such a size that when the apparent size of the target appears to be equal to that of the standard, the actual target is located at the distance for which the standard has been gauged. The standard can be a series of hairline hashmarks or curved lines in a reticle, a solid object like the front sight post on a rifle, or less commonly, an open figure which can be positioned over the target image.

The device concept developed during this project was a series of discrete holes (perfectly circular) scaled for a common battlefield target at fixed ranges. The razor-edged holes would eliminate the problem of stadia lines which have dimension which in turn introduces ambiguity as to exactly where the target image should be fit. As will be detailed below, such a device was developed which satisfied the design implications enumerated earlier.

What follows are the descriptions of three experiments supporting the device development. Experiment 1 provided a baseline of soldiers' unaided eye range estimation abilities. Experiment 2 was a pilot test of the effectiveness of the ranging device. Also provided in the description of Experiment 2 are details of the development of the device and its subsequent modification. Experiment 3 compared the two versions of the device with unaided eye estimates of experienced soldiers.

EXPERIMENT 1

The purpose of this experiment was to establish a baseline of range estimation ability for soldiers who had just completed training in range estimation techniques. Two different procedures were used to elicit range estimates. The Free Choice procedure allowed soldiers to choose any range values for their estimates. The Multiple Choice procedure constrained choices to a small set of range values as would be the case for a ranging device scaled for specific ranges.

Method

Subjects. Forty Initial Entry Training (IET) soldiers were selected at random from M203 grenade launcher training classes conducted at Fort Benning, Georgia. All soldiers were tested immediately after they had completed M203 qualification. During their course of instruction, the soldiers had completed a two hour block of instruction in range estimation. Instruction consisted of a lecture in the appearance of objects, flash-to-bang, and fixed interval (100 m) methods of land-based range estimation (see FM 23-31). The lecture was followed by a practical exercise in which soldiers used these methods to estimate the range to six plywood panels between 75 and 500 meters over terrain consisting of grassy areas, a section of roadway, and a large pond. The practical exercise did not provide multiple opportunities for range estimation, instructor critique, and retest.

Procedure. A 400 m section of straight, level roadway was marked with subdued paint at 50, 75, 100, 125, 150, 175, 200, 250, 300, and 350 m. These markings were not visible from observation point. A 1.778 m tall research assistant, dressed in neutral gray and light pastel colors, served as the target and moved from point to point in randomly determined orders. These movements were made with the observers facing away from the measured stretch of road.

Observers were moved to the observation point in groups of four and were told to use the methods learned in their range estimation class to determine the distance from themselves to the target. Twenty soldiers provided estimates under each procedure described below:

(a) Free Choice Procedure. Estimates were written on an answer sheet consisting of 10 blank lines numbered 1 to 10, one line for each of the 10 ranges of the series. Observers were not informed of the possible range values of the series.

(b) Multiple Choice Procedure. Answer sheets consisted of ten lines numbered 1 to 10. Each line listed the ten ranges in the following order: 50, 75, 100, 125, 150, 175, 200, 250, 300 and 350. Observers circled their choices on the line number corresponding to the current trial.

Choosing the same range more than once was allowed. Observers were not informed during the trials whether their estimates were correct, but were provided the correct estimates at the conclusion of the experiment.

A trial consisted of the four observers (two under each procedure) moving to the observation point, receiving their answer sheets, making a range estimate, and recording their answers. Answer sheets were then collected, and the observers were moved to a waiting area and monitored so they did not discuss their answers. Out of sight of the observers the target moved to a new position. Another trial then began. Data collection was conducted on two clear days.

Results

The major findings are shown in Table 1. For 50, 75, and 100 m target distances, Free Choice observers tended to judge targets as being closer than they were. For targets beyond 100 m, estimates of range were greater than the actual range with the crossover point from under- to overestimation occurring at 125 meters. The marked tendency to make biased estimates also was shown in the low rate of successful range estimation. With the exception of the 50 m target, the rate for Free Choice observers correctly estimating at each range was between 5 and 15 percent.

In contrast, the Multiple Choice group showed a higher rate of correct estimates--between 10 and 60 percent--for all targets except the 50-m target. Maximum rates of correct range estimation occurred for the 50-m and 350-m targets (75 and 60 percent respectively), reflecting anchoring at the extremes of the range scale values. End point anchoring appears to have occurred only at the 50-m range for the Free Choice group (85 percent rate of correct estimations).

The magnitude and pattern of estimation biases evident in the Multiple Choice observers differed from those in the Free Choice group. The data in Table 1 show a tendency for range underestimation at the lower and upper ends of the range scale for the multiple choice soldiers. A bias towards overestimation occurred at 175, 200 and 250 m, and also at the 50 m endpoint. In addition, the magnitudes of these biases are less pronounced for the Multiple Choice observers, as is evident from the mean absolute error data in column 1 of Table 1.

These different patterns of estimation errors are depicted in Figure 1 which shows geometric mean range estimates plotted against actual range values. The diagonal line represents the points of correct range estimation. Geometric means are shown here to allow comparison with other published research which report logarithmically transformed data. The data for both groups of observers show that apparent distance to the target increased linearly as actual distance increased. Both sets of data are well fit by a linear function ($r = .99$ for each set of data). The slope of the Multiple Choice function is .935 which is very close to the 1.00 slope of the diagonal, correct estimate straight line function.

The magnitudes of estimation errors were differentiated also by the Free versus Multiple Choice response procedure. The Free Choice group showed a strong tendency to make larger errors at longer target distances, reflected in a Pearson correlation coefficient between range and mean absolute error of .97, $p < .01$. For range estimates made using the multiple choice procedure, no

Table 1

Range Estimation Success and Error Rates and Error Magnitudes
for Free Choice and Multiple Choice Observers

	Mean Absolute Error (m)		Percentage of Correct Estimates		Percentage of Estimates Within ± 5 m of Range		Percentage of Estimates Within ± 20% of Range		Percentage of Underestimates		Percentage of Overestimates	
Range	FC	MC	FC	MC	FC	MC	FC	MC	FC	MC	FC	MC
50	2.5	7.5	85	75	85	75	90	75	10	0	5	25
75	23.0	20.0	10	40	25	40	35	75	45	35	45	25
100	35.8	29.7	10	25	10	25	25	25	50	50	40	25
125	35.3	30.0	5	20	10	20	75	65	40	40	55	40
150	56.5	37.5	10	15	10	15	25	25	45	40	45	45
175	69.3	50.0	10	20	10	20	25	50	30	25	60	55
200	80.8	58.8	5	10	5	10	20	25	30	40	65	50
250	110.8	42.5	10	40	10	40	45	70	15	15	75	45
300	132.5	31.3	10	50	10	50	35	65	15	35	75	15
350	121.3	25.0	15	60	15	60	40	80	20	40	65	0

NOTE: FC = Free Choice Group (n = 20)
MC = Multiple Choice Group (n = 20)

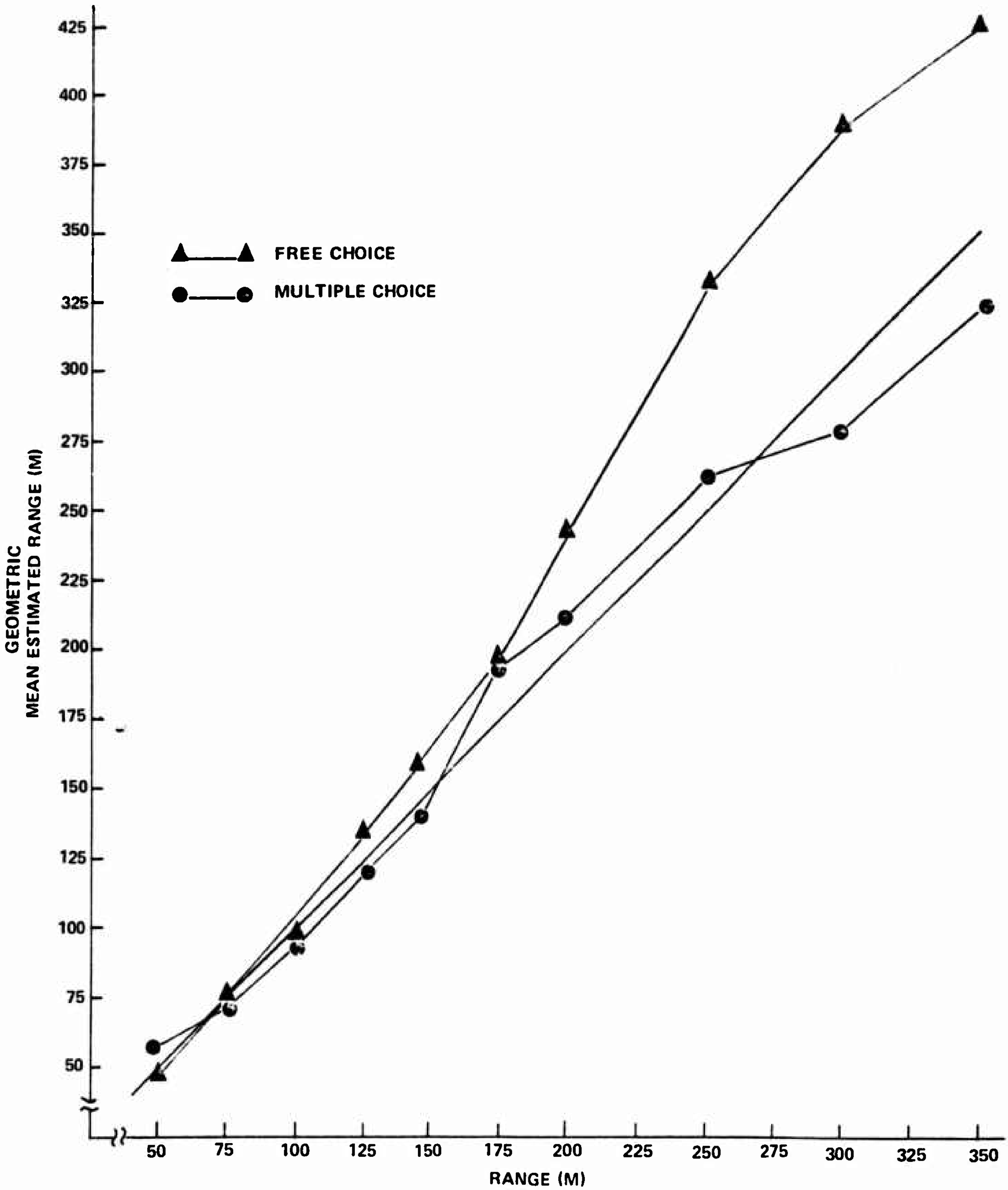


FIGURE 1. GEOMETRIC MEAN ESTIMATED RANGE FOR FREE CHOICE AND MULTIPLE CHOICE ESTIMATES IN EXPERIMENT 1. DIAGONAL LINE REPRESENTS EXACT RANGE ESTIMATES.

systematic covariation was demonstrated between range and absolute error of judgement, (r = .34, p >.05).

An additional analysis of range estimation errors that was particularly appropriate for M203 skill assessment was establishing the percentage of judgments that were within the burst radius of a grenade round. Since the effective casuality radius of most grenage rounds is 5 m, an estimate of range must be at most 5 m from the intended target. As is evident from column 3 of Table 1, few estimates in the Free Choice group were accurate to within 5 m of the ranges sampled. The singular exception is the target range of 50 m. On the other hand, the Multiple Choice group showed considerably higher rates of acceptible estimates (10 to 60 percent as compared to 5 to 25 percent for the Free Choice group).

For the purposes of comparison, a larger bracket of plus or minus 20 percent of each target range was established for assessing the performance of the observers under both procedures. This bracket is one frequently reported in range estimation literature (Thompson, 1982). As expected, the relatively better performance of the Multiple Choice group is maintained. Differences between the two procedures' results appear to diminish in the midrange values while end point anchoring is again shown in the Multiple Choice group's estimates.

Discussion

The intent of this experiment was to determine baseline range estimation performance. The Multiple Choice procedure was included to suggest some features of a ranging device. These features are a delimited set of estimatable ranges and some memory mechanism whereby the observer keeps track of the potential range values to be chosen or those already attempted. Observers in the Multiple Choice group were given the listing of ranges to be estimated and thus had to choose from a small set of response alternatives. In addition, they had a cumulative account of their choices and the opportunity to use a range value more than once.

It is not surprising, therefore, that the performance of the Multiple Choice group was almost exclusively better than the Free Choice group. However, the percentages of multiple choice observations within 5 m or within 20 percent of the range probably reflect some inflation due to guessing. This benefit due to the Multiple Choice procedure is most pronounced for the range values exceeding 200 m. A problem which cannot be addressed by these data is the degree or magnitude of the inflation. The data from this experiment do show that upper end point anchoring inflates the success rate for range estimation by a factor of 4 using mid range values as the comparison; this factor reduces to 2 when the scoring interval is a bracket of plus or minus 20 percent of the range value.

The effects of anchoring are less pronounced for these range estimation data than for size estimation reported by Underwood (1966). In that experiment, subjects were given upper and lower end point scale values; estimates of the sizes of rectangles showed overestimation of small figure sizes and the underestimation of larger figure sizes. Underwood reported an orderly change from over- to underestimation, whereas the Multiple Choice range data in the present experiment showed initial overestimation followed by two phases of underestimation, the second of which is consistent with that reported by Underwood. Had the Multiple Choice subjects been given range choices well below 50 and well in excess of 350, the anchoring effects may have been less pronounced.

Of particular interest is the Free Choice group's increase in error of estimation as range increased. These data are at variance with those reported by Gibson and Bergman (1954) who asked Air Force enlistees to use the free choice procedure to estimate distances to signpost-type targets between 52 and 395 yards away. Their observers showed a consistent tendency for underestimation, but magnitude of error was not related to distance to the target. The plot of the Gibson and Bergman estimated range against actual range bears more resemblance to the present Multiple Choice group function than to the procedurally similar Free Choice group's function. Noteworthy, also, is the fact that the Multiple Choice group's data in the present experiment showed no correlation between magnitude of error and target distance.

An interpretation of the findings of this experiment is made difficult by incomplete theories of space perception. However, the Multiple versus Free Choice group differences may be attributable more to methodological issues than to theoretical ones. Gibson and Bergman's (1954) subjects viewed a field of 18 targets, all of which were permanently in view. Once the observer had surveyed the target field and established upper and lower distance bounds, target estimates were made relative to one another within this frame of reference. In the present experiment, Multiple Choice subjects were given cues to the dimensions of the field of view (50 to 350) when referring to the answer sheet. It is reasonable to assume, then, that the Multiple Choice procedure and Gibson and Bergman's procedure established a limited, stable set of range estimate values which served to stablize the estimation process. The Free Choice procedure had fewer mechanisms to reestablish the estimation set and estimates were made without the benefit of an external reference and boundary limits.

In the absence of any information on what methods the Free Choice subjects used to make their estimates, speculations on the processes which generated the results are limited. For instance, had the observers used the fixed interval method exclusively, the Free Choice group's results are consistent with overestimations inherent in that method (Gilinsky, 1951) or in the observers' use of a fixed interval not of the required 100 m but of 125-130 m. On the other hand, the explanation may lie in the recent experience of the observers. Both groups arrived at the estimation experiment directly from qualification. The soldiers had estimated distance to and fired at large targets (e.g., large panels surrounding a window, disabled tanks) at ranges of 100 to 300 m. The overestimation of the Free Choice observers may be due to their estimating ranges to a much smaller target. Since the size of objects is a cue to distance, the contrast between recent experience of large targets versus small targets of the current experiment (range values remaining roughly equivalent) would introduce overestimation errors. That is, a man size target viewed at a given distance would be seen as being further away than a large panel viewed at the same distance.

The results of this experiment point out two important characteristics of range estimation. The first is that estimation of distance to a series of randomly positioned man-sized targets yields overestimation of distances beyond 100 m. Estimates short of that distance are generally quite accurate. The second characteristic is that some mechanism which provides appropriate cues to range values serves to reduce errors of estimation. In this case the mechanism was a list of range values.

Since the accuracy of range estimation was inflated by the multiple choice procedure, the actual range estimation capability of newly trained grenadiers probably is reflected in the Free Choice group's data. Clearly, these grenadiers would achieve low levels of firing accuracy were they to use these estimates to set sight elevation on their weapons. The data indicate a need to develop a simple device which could provide estimates of range values within the 50 to 350 m field of fire of the M203.

EXPERIMENT 2

The results of Experiment 1 pointed to the need for a ranging aid for the M203, especially for targets located beyond 125 m. The considerations for such a device are that it should be mountable on existing grenade launchers, simple in design, and inexpensive (which eliminates optical devices). A variety of stadiametric aids have been developed (i.e., the choke sights for the M72 Light Antitank Weapon, the M67 90mm and M40A2 106mm recoilless rifles). But a study by Giordano at the US Army Human Engineering Laboratory (1976) pointed out three components of ranging error in the use of stadiametric devices: (a) the thickness of stadia lines, (b) unsteadiness of handheld devices, and (c) target motion accompanied by target obscuration. A fourth component can be added: the spherical aberration and image degradation resulting from plastic enclosed stadiametric devices (e.g., the M72 stadiametric sight).

Given these limitations, a different conceptualization of stadiametric principles was developed for the M203 ranging device. This was to use a series of sharp edged, circular holes in heavy sheet metal; hole sizes were to be gauged according to stadiametric principles and scaled according to a man-sized target. This design would eliminate the problems associated with thick stadia lines and embedding stadia in less than optical quality plastic. The following describes the device and a pilot study of its effectiveness.

Three measures were critical for the development of the ranging device: the size of the target to be sighted, the distance from the eye to the target, and the distance from the eye to the sighting device. A target height of 1.778 m (5 ft 10 in.) was selected as representing the height of the average enemy soldier. Target width, however, was not considered to be a relevant parameter. The range of target distances selected for the ranging device was 50 to 350 m. Longer target distances (200 to 350 m) were chosen to coincide with existing settings on the M203 quadrant sight; the increment of 50 m between these target ranges maximized discriminable differences among the smaller ranging device hole sizes. The shorter target distances (50 to 200 m in 25 meter increments) also were chosen to coincide with range settings on the quadrant sight. However, resulting hole sizes were judged to be discriminable with 25 m target range increments.

The final measurement, eye-to-sighting device distance, presented a design problem--whether to place the sighting device at a moveable or fixed position on the M203. One solution would have been to construct the sighting device so it could be adjusted to a fixed distance from each firer's eye. Since the construction of the M203 would not easily accommodate such a design, the fixed position alternative was chosen. The major consideration was the availability of the leaf sight mounting base at the forward end of the hand guard. Constructed to exactly the same dimensions as the leaf sight and using the existing mounting hardware, the sighting device easily could be exchanged for the seldom used leaf sight. Given this design decision, an average eye-to-leaf sight measurement was obtained on 30 soldiers undergoing M203 training. Measurements were made with the firer's nose touching the charging handle of the M16A1 rifle. Mean distance from the eye lid to the near face of the leaf sight was found to be 44.87 cm ($\underline{SD}$ = 0.42).

Once the above set of three measurements was established, calculation of the hole diameters was based on the following trigonometric proportion: the ratio of the actual target size to the selected eye-to-target distance is equal to the ratio of hole diameter to eye-to-ranging device distance. Solving for hole size, the formula is

$$\frac{(177.8)(44.87)}{TD \times 100} = D \qquad \text{(Equation 1)}$$

where

177.8 = fixed target height in cm
44.87 = fixed eye-to-sighting device distance in cm
TD = eye-to-target distance in meters (50 to 350 m)
D = ranging device hole diameter in cm

This proportion is based on a property of the right triangle defined by the target and its distance from the observer's eye. This relationship is depicted in Figure 2. At 44.87 cm on the longer leg of this triangle (in other words, the position of the ranging device from the firer's eye on the M203), the distance from the leg of the triangle to the hypotenuse is inversly proportional to the distance from the observer to the fixed-size target. This leg-to-hypotenuse distance represents the size of the target image at the ranging device. The diameter of the hole should, therefore, be exactly that size. Listed in Appendix A are the calculated and actual hole diameters for the first prototype.

A diagram of the sighting device and its placement on the M203 is shown in Figure 3. The device was fabricated from 16 gauge steel and blued to reduce glare. The holes were countersunk on the side facing away from the user to create sharp aperture edges.

Once the design specifications of the ranging device were determined, a small pilot study of its effectiveness was undertaken. This preceeded more extensive testing.

Method

A preliminary test was carried out to verify the utility of the device and to provide data for adjusting hole sizes or other features of the device. A target was constructed from an E-type rifle silhouette target extended on its bottom edge to create a 1.778 m tall figure. A 5 cm white strip was attached to the top of the head and along the bottom edge of the dark gray target to make the top and bottom edges clearly visible. The target was mounted on a pole so that the bottom edge was 31 cm off the ground. A level, straight 450 m stretch of roadway was marked off at 50, 75, 100, 125, 150, 175, 200, 250, 300, and 350 m in subdued markings not visible from the observation point. The ranging device was mounted on an inoperable (unfirable) M203 grenade launcher. Observations were made on clear days.

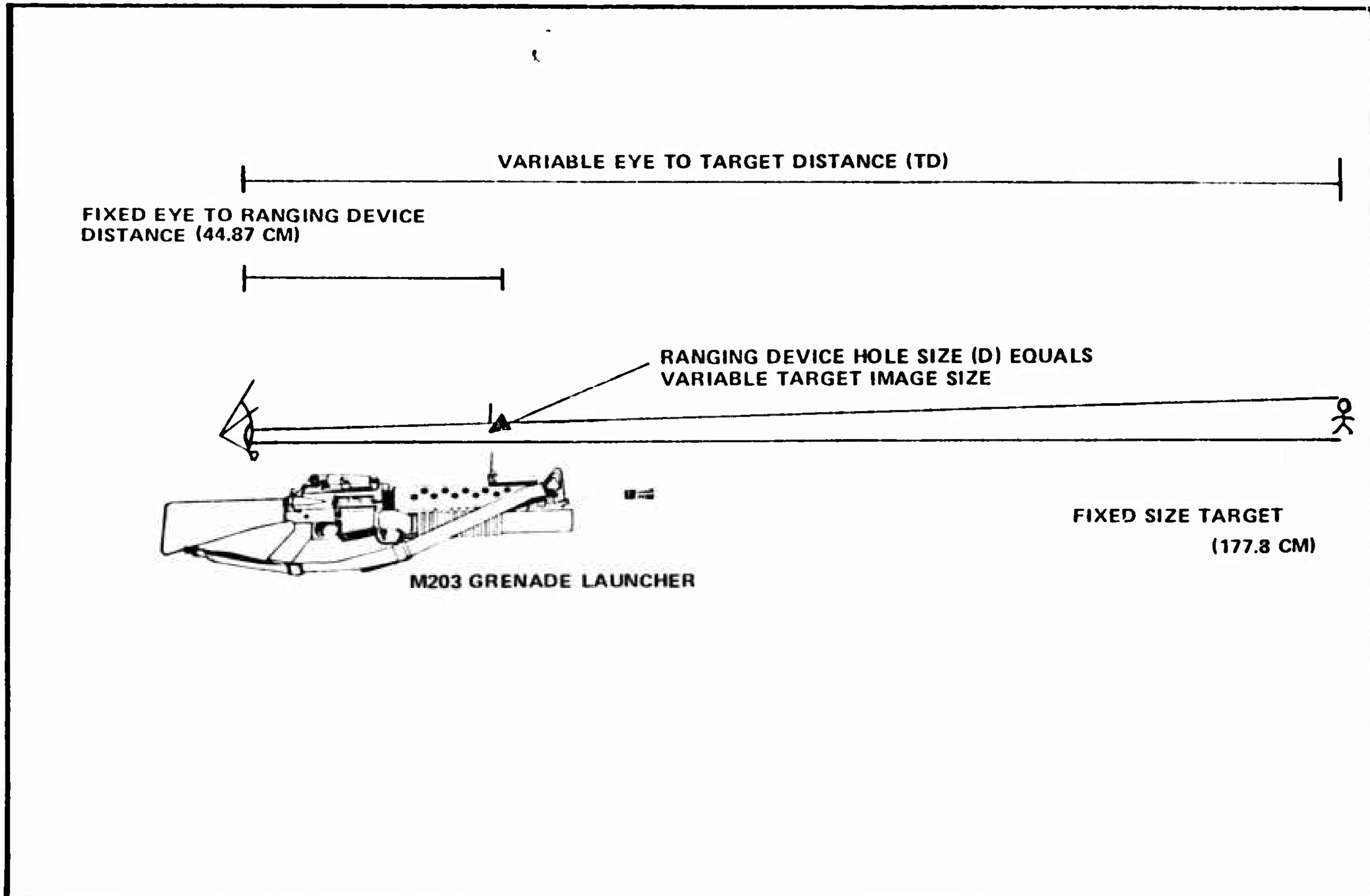


FIGURE 2. RELATIONSHIP BETWEEN TARGET SIZE, VARIABLE EYE TO TARGET DISTANCE, AND RANGING DEVICE HOLE SIZE (NOT TO SCALE).

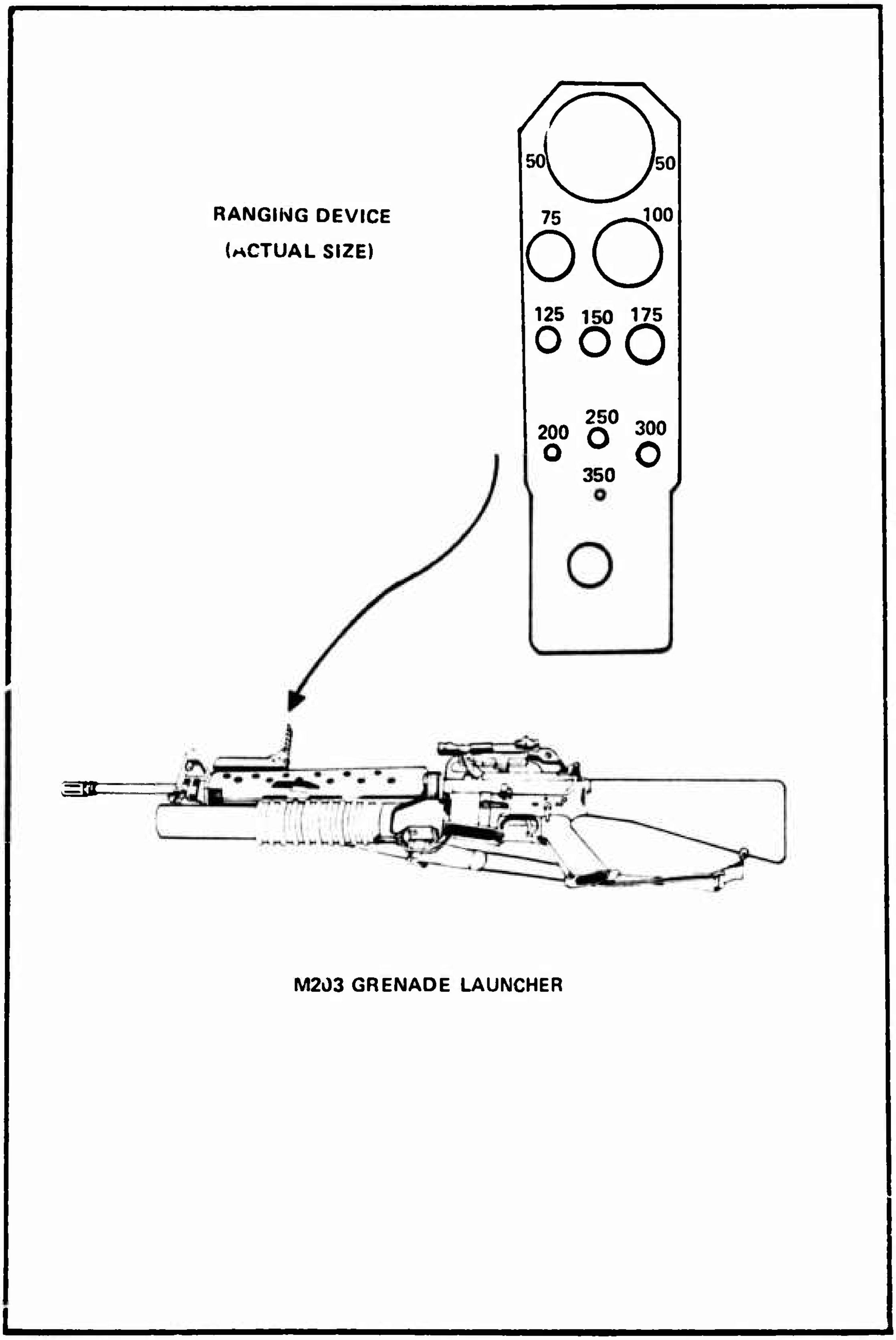


FIGURE 3. PLACEMENT OF RANGING DEVICE (SHOWN ACTUAL SIZE) ON THE EXISTING LEAF SIGHT OF M203 GRENADE LANUCHER.

Three civilian observers untrained in range estimation made judgments at each of the ten ranges. Three series of range estimates were carried out--two ascending sequences (50 to 350 m) and one descending sequence (350 to 50 m). One practice session preceeded the actual data collection.

The method of adjustment was used to generate range judgments. For all series of range estimation, a research assistant initially moved the target to a distance either less than or greater than a range marking on the pavement. For example, if the range estimate were to be made for 100 meters, the target's initial position might be 85 m or 115 m. Both the under- and over-positioning of the target and the size of the displacement were randomly selected.

The observers were informed which range was to be estimated. The observer positioned his head against the stock so that his nose touched the charging handle. After selecting the correct hole on the ranging device, the observer looked through the hole at the target. His task was to fit the target image into the hole so that the target's upper and lower white stripes just touched the top and bottom of the hole. This was accomplished by requesting that the target be moved either closer to or further away from the observer's position. As many adjustments as required were allowed. Requests for adjustments were communicated to an experimenter at the observation point; the experimenter in turn communicated to the assistant by hand signals. Data collection took place over two days.

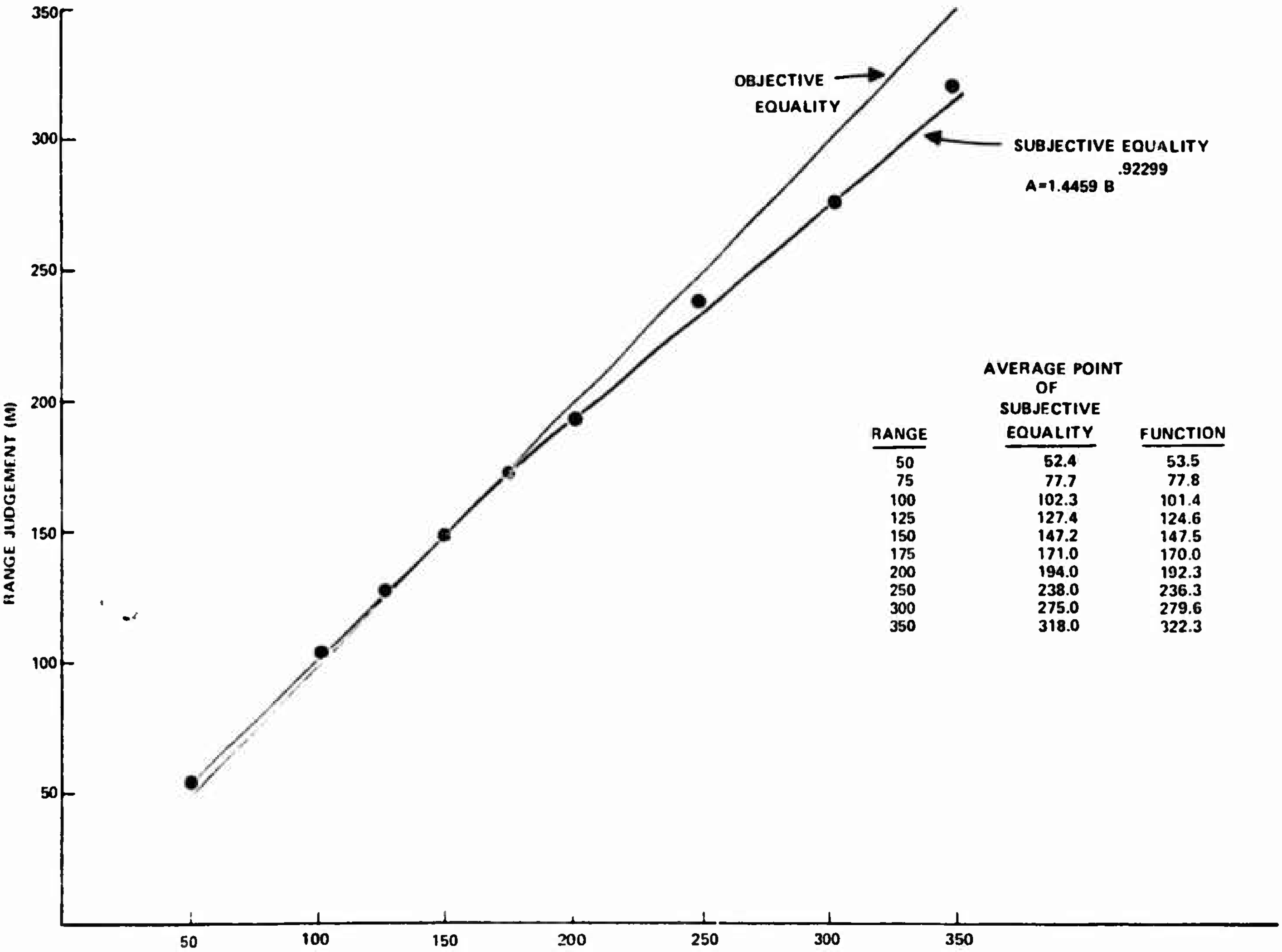
Results and Discussion

Once the observer was satisfied that the image size corresponded to the hole size (i.e., the target "just fit" into the hole), the distance from the observer to the moveable target was measured. Since the observers noted a learning effect using the device, only the data from the last two estimation sequences--one ascending and one descending--were analyzed. For each range, the arithmetic mean of the observers' six target settings (two target settings per observer across three observers) was computed. Each mean represents the average point of perceptual equivalence of the target image viewed at a given distance with the ranging device hole size for that distance. In the psychophysical literature this perceived equivalence of a variable stimulus and a standard stimulus is referred to as the point of subjective equality (PSE).

The range values of the ten PSEs are presented in Figure 4. The data show that observers placed the target beyond the actual range at 50, 75 and 100 m, a psychophysical phenomenon referred to as positive constant error. Between 150 and 350 m observers, on the average, positioned the target short of the intended range (negative constant error). As shown in the figure, positive constant error decreased and negative constant error increased as range increased. These data points were fit to a power function shown in Equation 2

$$A = 1.4459\ B^{.92299} \qquad \text{(Equation 2)}$$

which closely describes the data, as shown in the column labeled "Function" of the figure insert. These data demonstrated the observers were systematically



RANGE	AVERAGE POINT OF SUBJECTIVE EQUALITY	FUNCTION
50	52.4	53.5
75	77.7	77.8
100	102.3	101.4
125	127.4	124.6
150	147.2	147.5
175	171.0	170.0
200	194.0	192.3
250	238.0	236.3
300	275.0	279.6
350	318.0	322.3

FIGURE 4. FUNCTION DESCRIBING AVERAGE POINT OF SUBJECTIVE EQUALITY OF TARGET IMAGE AND RANGING DEVICE HOLE SIZE AS A FUNCTION OF ACTUAL RANGE FOR THE THREE OBSERVERS OF EXPERIMENT 2.

underfitting the target image (i.e., the image did not touch the edges of the hole) at short ranges and overfitting the image at longer ranges.

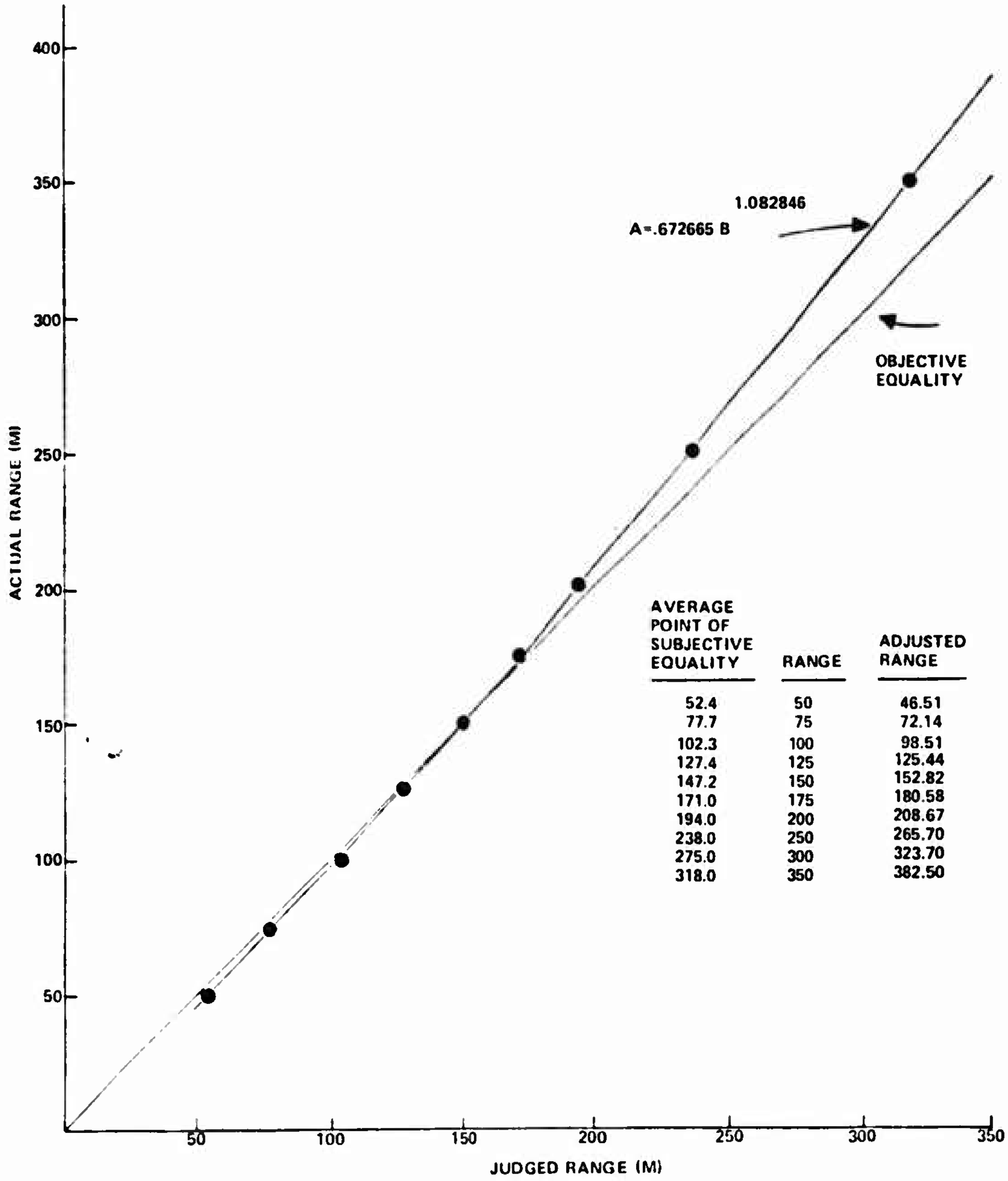
The systematic change in constant error suggested that a function could be developed which would provide an intermediate result from which new hole sizes could be determined. This intermediate output needed to be a new set of PSEs. In other words, the new equation would need to input some objective range to be estimated and output that range value adjusted for perceptual constant error. From these adjusted range values the hole size for a new ranging device could be calculated using Equation 1.

Figure 5 presents the power function fit to the average PSEs as input and the ranging device values between 50 and 350 m as output. Once Equation 3

$$A = .672665\, B^{1.082846} \qquad \text{(Equation 3)}$$

was developed, the values 50, 75, 100, 125, 150, 175, 200, 250, 300, and 350 were input and the "adjusted ranges" output. For example, for a range estimate of 50 m to be produced, the hole needed to be drilled as if the target range to be estimated were 46.51 m. For each of the ten ranges selected for the device, adjusted range values were calculated. These are shown in the insert in Figure 5.

Adjusted hole sizes were calculated using Equation 1 and the adjusted range values. These hole sizes are shown in Appendix A. As compared to the original holes, for the shorter ranges the hole size is increased and for longer ranges hole size is decreased. Thus, it was anticipated that underfitting and overfitting of the target images would be minimized or eliminated.



AVERAGE POINT OF SUBJECTIVE EQUALITY	RANGE	ADJUSTED RANGE
52.4	50	46.51
77.7	75	72.14
102.3	100	98.51
127.4	125	125.44
147.2	150	152.82
171.0	175	180.58
194.0	200	208.67
238.0	250	265.70
275.0	300	323.70
318.0	350	382.50

FIGURE ˉ FUNCTION DESCRIBING ACTUAL RANGES ADJUSTED FOR PERCEPTUAL BIAS AS A FUNCTION OF RANGE TO BE JUDGED (EXPERIMENT 2).

EXPERIMENT 3

The purpose of the third experiment was to compare the accuracy of range judgments using the original (uncorrected) and adjusted hole size (corrected) devices with unaided eye judgments provided by the same soldiers. Training techniques for fitting images to hole sizes was considered but dismissed after a pilot test indicated no apparent improvements with brief periods of training.

Method

Subjects and Procedure. Sixteen infantry soldiers assigned to combat ready units who had experience in firing the M203 grenade launcher served as subjects. All observations were made on a tactical aircraft landing strip at Fort Benning, Georgia. The asphalt runway, devoid of any lane markings, was 1200 m long and 30 m wide in a cleared, grassy area approximately 2000 m by 300 m. From an observation point on the pavement, distances of 50, 75, 100, 125, 150, 175, 200, 250, 300, and 350 m were marked off in subdued paint on the runway.

The range estimation procedures were administered as a 2 x 3 x 10 fixed factor within-subjects design. The factors were direction of target movement (out from the observer or in towards the observer), viewing condition (unaided eye, corrected, and uncorrected devices), and target range (10 ranges). All subjects provided their unaided eye range estimates first. For the blocks of trials with the ranging devices, order of use of the devices was counterbalanced; half the subjects viewed the target with the corrected device first, the other half with the uncorrected device first. Initial position of the target (0 m or 425 m as described below) was the same under all three viewing conditions and was counterbalanced across subjects.

The target was a soldier wearing fatigues, boots, and cap, whose total height was 1.80 m. All observations with the unaided eye were conducted with the observer standing at the observation point. Range estimates using a device were made with the device attached to the leaf sight mount of an inoperable M203. For these estimates, the observer was seated and the M203 supported at shoulder height.

Two subjects were tested each day. Each pair of experimental subjects was randomly assigned to an order of target movement (out-in or in-out). For each of the three phases of the experiment (unaided eye, corrected and uncorrected devices), the procedures were administered individually. For the out-in sequence, the target's initial position was immediately in front of the observer. Target movement was away from the observer. Once reaching the furthest range, the target was repositioned at 425 m and then moved toward the observer. The in-out sequence merely interchanged the order of movement so that the initial target position was at 425 m.

This procedure at each phase of the experiment provided two distance judgments per observer for all 10 target ranges. During unaided eye estimates, the experimenter informed the observer what range was to be estimated. The target advanced or retreated slowly until the observer judged that the intended range was reached. At that point he told the experimenter to halt the target and the experimenter in turn signalled the target to stop; the observer, communicating to the target through the experimenter, adjusted the target back and forth until his final judgment was reached. The target dropped a marker chip to mark his location and then began advancing or retreating from that point to the next target range in the 10-range ascending/descending sequence.

The movement, adjustment, and marking procedure was identical when the observer was using the ranging devices. Since the observer was familiar with the procedure, the only additional instructions necessary were the directions in use of the ranging devices. The procedural details in the use of the device developed in Experiment 2 were followed in the final two phases of the present experiment. That is, the tip of the nose was touching the edge of the M203 charging handle. The observer viewed the target through the hole indicated to him by the experimenter. As much time and as many adjustments as necessary to "just fit" the target image within the hole were permitted.

Once the observer had completed all of his estimates, in and out or vice versa, he moved to a waiting area facing away from the landing strip. The distances of the marker chips from the observation point were measured and recorded. The marker chips were collected as the distances were measured. The second observer then moved into position and completed that phase of the experiment. The soldiers did not review their data until the completion of the experiment.

Results

Prior to statistical analyses, the data were examined for extreme values and departures from normality. For some combinations of conditions of the experiment, the data were moderately skewed. In order to stabilize the variances and normalize the data, base 10 logarithmic transformations were carried out. All statistical analyses were then completed using the logarithmic values. Unless otherwise noted, mean values reported are geometric means.

Range Estimates. One method of assessing the relative differences among the unaided eye and the devices is to represent the data as estimates of observer-to-target distance. These mean estimates are plotted in Figure 6 as a function of the actual distance of the target from the observer.

An analysis of variance was conducted to test specific eye and device differences and to examine systematic trends in the range estimates. This analysis is shown in Table 2. The ability of observers to discriminate the various target distances is shown by the significant main effect for range, $F(9,135) = 1185.92$, $p < .0001$, which is composed of linear, $F(1,15) = 1465.83$, $p < .0001$, and quadratic components, $F(1,15) = 928.96$, $p < .0001$. These linear and quadratic trend components, which mathematically take into account the change of range increment from 25 to 50 m beyond 200 m, indicate that systematic biases emerge towards under- and overestimation of range. However, these biases are a joint function of range, the conditions of viewing, and the direction of target movement. Since neither the three way interaction, $F(18,270) = 1.43$ $p = .12$, nor the Target Direction x Method of Viewing interaction, $F < 1$, were significant, examination of the remaining two way interactions involving range revealed the joint effects.

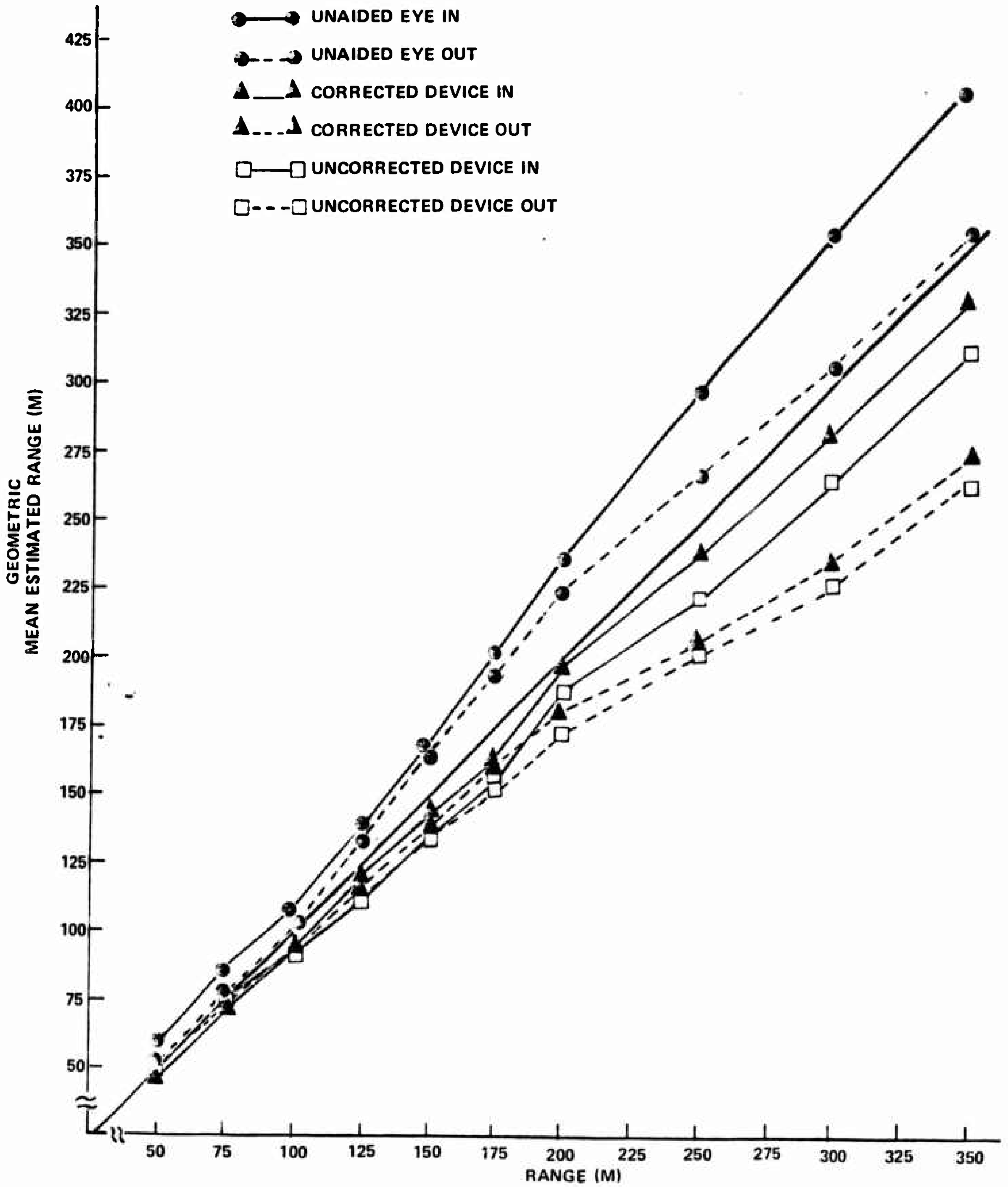


FIGURE 6. GEOMETRIC MEAN ESTIMATED RANGE IN METERS FOR INBOUND AND OUTBOUND TARGETS UNDER THE THREE VIEWING CONDITIONS OF EXPERIMENT 3.

Table 2

Summary of Analysis of Variance of Estimated Range under Various Viewing Conditions

Source	Sum of Squares	df	Mean Square	F	Probability
IO (Direction of Target Movement)	0.24384	1	0.24384	13.58	0.0022
Error	0.26942	15	0.01796		
M (Method of Viewing)	1.53472	2	0.76736	8.34	0.0013
Error	2.75870	30	0.09196		
ED (Eye-Devices Comparison)	1.51751	1	1.51751	8.93	0.0092
Error	2.55011	15	0.17001		
CU (Corrected-Uncorrected Device Comparison)	0.01718	1	0.01718	1.24	0.2836
Error	0.20859	15	0.01391		
R (Range)	56.85154	9	6.31684	1185.92	0.0000
Error	0.71908	135	0.00533		
L (Linear Trend)	52.28210	1	52.28210	1465.83	0.0000
Error	0.53501	15	0.03567		
Q (Quadratic Trend)	4.21000	1	4.21000	928.96	0.0000
Error	0.67979	15	0.00453		
IO x M	0.01582	2	0.00791	0.35	0.7062
Error	0.67444	30	0.02248		
IO x R	0.14532	9	0.01615	9.45	0.0000
Error	0.22854	135	0.00169		
IO x L	0.09788	1	0.09788	12.65	0.0029
Error	0.11609	15	0.00774		
IO x Q	0.02392	1	0.02392	15.45	0.0013
Error	0.02322	15	0.00155		
M x R	0.22066	18	0.01226	3.52	0.0000
Error	0.94010	270	0.00348		
ED x L	0.14066	1	0.14066	3.75	0.0720
Error	0.56308	15	0.03754		
ED x Q	0.02221	1	0.02221	4.17	0.0592
Error	0.07992	15	0.00533		

Table 2 - Continued

Source	Sum of Squares	df	Mean Square	F	Probability
CU x L	0.02866	1	0.02866	7.87	0.0134
Error	0.05470	15	0.00365		
CU x Q	0.01826	1	0.01826	14.96	0.0015
Error	0.01183	15	0.00122		
IO x M x R	0.04949	18	0.00275	1.43	0.1169
Error	0.51921	270	0.00192		

The direction of target movement (toward or away from the observer) emerges as an influence on range estimates as shown by a significant Target Direction x Range interaction, $F(9,135) = 9.45$, $p < .0001$. At ranges less than 175 m, direction of target movement differences were negligible. As range increased to 350 m, however, target movement away from the observer yielded increasingly shorter range estimates as compared with estimates on the same distance in-bound targets. This in-out difference over range is evident in Figure 6 and is supported by statistically significant differences in linear slope, $F(1,15 = 12.65$, $p = .0029$, and the levelling off tendency, $F(1,15) = 15.45$, $p = .0013$, of the in and out conditions.

The Method of Viewing x Range interaction was statistically significant, $F(18,270) = 3.52$, $p <.0001$. The sum of squares of this interaction was decomposed into interactions of trend components and specific hypotheses concerning method of viewing differences. The first hypothesis was an a priori contrast (planned comparison) between the unaided eye range estimates and the averaged estimates for the two devices. The second contrast, orthogonal (statistically independent) to the first, was the difference in estimates between the two devices. These contrasts asked two meaningful questions. The first was whether the devices were an improvement over reckoning distance without the use of an instument; the second question was whether the devices differed in any significant way.

Overall, the average range estimate with the eye was greater than the average estimate for the devices, $F(1,15) = 8.93$, $p = .0092$. The analysis also revealed that the differences between the eye and devices were statistically indistinguishable across all ranges. Both the Eye-Devices x Linear Trend interaction, $F\ (1,15) = 3.75$, $P = .0720$, and the Eye-Devices x Quadratic Trend interaction, $F(1,15) = 4.17$, $p = .0592$, were statistically nonsignificant. Differences did emerge, however, in the trends for the corrected and uncorrected devices. The corrected device data have a steeper linear slope, $F(1,15) = 7.87$, $p = .0134$, and have less curvature away from exact range estimates, $F(1,15) = 14.96$, $p = .0015$, than those of the uncorrected device.

In contrast to the above analyses which make comparisons between range estimates under various experimental conditions, range estimates with the unaided eye and corrected device for incoming targets were compared with the actual distances to the targets (represented by the diagonal line in Figure 6). This type of analysis is a simultaneous test for chance departures of the ten mean estimated ranges from the ten distances chosen for estimation. Using an analysis of variance technique described by Lewis (1960, pp. 372-375), unaided eye incoming target estimates were shown to be significantly greater than the actual distances, $F(10,135) = 6.20$, $p <.001$, and the corrected device incoming target estimates were significantly less than the actual distances, $F(10,135) = 5.95$, $p < .001$. Across all ten ranges under investigation, then, the obtained estimates under these two viewing conditions are significant departures from veridical or exact range estimaes.

Magnitude of Estimation Errors. The previous section dealt with the average target placement for the 10 distances selected for range estimation. Another method of assessing eye and device differences is to examine the magnitude of errors in making these range estimates. For this analysis, the absolute (unsigned) error in estimation is appropriate. Whether the estimation is short or beyond the intended range is important for actual firing of the M203, but is immaterial in assessing the comparative merit of the devices. Absolute error also offers a straight-forward way of using a logarithmic transformation of the data. The geometric mean absolute errors under all conditions of the experiment are shown in Figure 7. The same analysis of variance design used to evaluate the range estimation data was used to evaluate the absolute error data and is summarized in Table 3. Many of the comparisons yielded conclusions comparable to those for the range estimates. The three way interaction of Direction of Target Movement x Method of Viewing x Range was not significant, $\underline{F} < 1$, nor was the interaction of Direction of Target Movement x Method of Viewing, $\underline{F}(2,30) = 1.35$, $\underline{p} > .05$. Target range, and its interactions with the other factors and planned comparisons, again was responsible for a major portion of the variability in the data.

Errors in estimation occurred at all ranges. The main effect for range was statistically significant in both its linear trend, $\underline{F}(1,15) = 305.58$, $\underline{p} < .0001$ and its quadratic trend, $\underline{F}(1,15) = 30.50$, $\underline{p} = .0001$, indicating that errors of estimation increased with range in a predominately linear or directly increasing fashion. As was the case with the range estimates themselves, the joint influence of other factors of the experiment and range was of particular interest.

Figure 8 shows the effect of the direction of target movement on errors across the 10 range values and averaged over the three methods of viewing. The movement of the target away from the observer resulted in errors at 200 m and beyond that were 2.5 to 6 times greater than those at less than 200 m. When the target's initial position was at its furthest point and moved toward the observer, size of errors down to 200 m did not exceed twice the error for the 50 to 200 m targets. This difference in error magnitude between the in and out conditions was statistically significant in its linear trend, $\underline{F}(1,15) = 56.18$, $\underline{p} < .0001$, and showed no tendency to accelerate or decelerate as range varied, as indicated by the nonsignificant Direction of Target Movement x Quadratic Trend interaction, $\underline{F}(1,15) = 3.21$, $\underline{p} = .09$.

When the in-out direction of target movement effect was held constant, the Method of Viewing x Range interactions was evident. This view of the error magnitudes is depicted in Figure 9. A significant interaction of the eye-devices comparison with trends over range was obtained for both the linear, $\underline{F}(1,15) = 43.86$, $\underline{p} < .0001$, and quadratic components of trend, $\underline{F}(1,15) = 4.65$, $\underline{p} = .0477$. Not only are errors larger in magnitude for the eye than for the devices considered as a group, but the size of errors tended to level off at about 40 m for targets at 200 m and beyond. In comparison, errors are small with use of the devices up to about 150 m, but then accelerate rapidly over the longer ranges. At 250, 300, and 350 m, the devices considered together offered no advantage over unaided eye estimates. In comparing the two devices, no differences in errors in range estimation precision were found between the two as shown in $\underline{F}$ ratios less than 1.0 for the Corrected-Uncorrected Comparison x Trend Components interations.

These statistical analyses offer a partial assessment of how well grenadiers would estimate range using any of the methods of viewing. An instructive comparison is to consider the first round hit rate had an average observer fired the M203 using the range estimates obtained during the

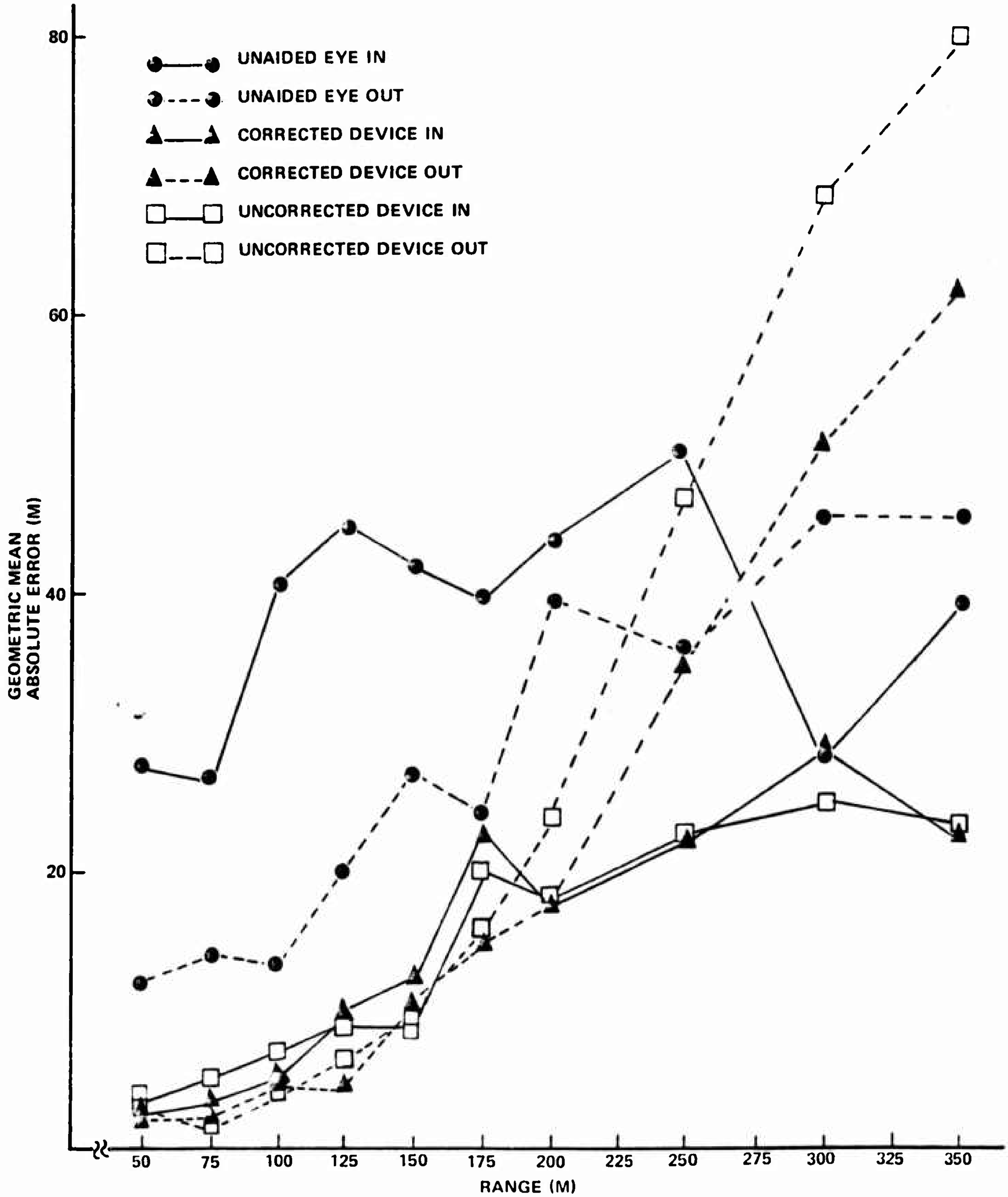


FIGURE 7. GEOMETRIC MEAN ABSOLUTE ERROR IN METERS FOR INBOUND AND OUTBOUND TARGETS UNDER THE THREE VIEWING CONDITIONS OF EXPERIMENT 3.

Table 3

Summary of Analysis of Variance
of Absolute Range Estimation Errors

Source	Sum of Squares	df	Mean Square	F	Probability
IO (Direction of Target Movement)	0.56979	1	0.56979	0.70	0.4148
Error	12.15121	15	0.81008		
M (Method of Viewing)	37.14066	2	18.57033	15.72	0.0000
Error	35.43746	30	1.18125		
ED (Eye-Devices Comparison)	36.94580	1	36.94580	21.33	0.0003
Error	25.98455	15	1.73230		
CU (Corrected-Uncorrected Device Comparison)	0.19488	1	0.19488	0.31	0.5863
Error	9.45291	15	0.63019		
R (Range)	102.63963	9	11.40440	72.06	0.0000
Error	21.36589	135	0.15827		
L (Linear Trend)	92.86930	1	92.86930	305.58	0.0000
Error	4.55873	15	0.30392		
Q (Quadratic Trend)	9.02076	1	9.02076	30.50	0.0001
Error	4.43683	15	0.29579		
IO x M	2.34103	2	1.17051	1.35	0.2737
Error	25.94962	30	0.86499		
IO x R	12.51743	9	1.39083	12.33	0.0000
Error	15.22642	135	0.11279		
IO x L	11.17050	1	11.17050	56.18	0.0000
Error	2.98254	15	0.19884		
IO x Q	0.24509	1	0.24509	3.21	0.0932
Error	1.14393	15	0.07626		
M x R	20.35246	18	1.13069	8.68	0.0000
Error	35.16142	270	0.13023		
ED x L	18.36670	1	18.36670	43.86	0.0000
Error	6.28170	15	0.41878		
ED x Q	0.60555	1	0.60555	4.65	0.0477
Error	1.95254	15	0.13017		
CU x L	0.00412	1	0.00412	0.02	0.9030
Error	4.02315	15	0.26821		

Table 3 - Continued

Source	Sum of Squares	df	Mean Square	F	Probability
CU x Q	0.04865	1	0.04865	0.41	0.5293
Error	1.75984	15	0.11732		
IO x M x R	2.11574	18	0.11754	0.81	0.6907
Error	39.28687	270	0.14551		

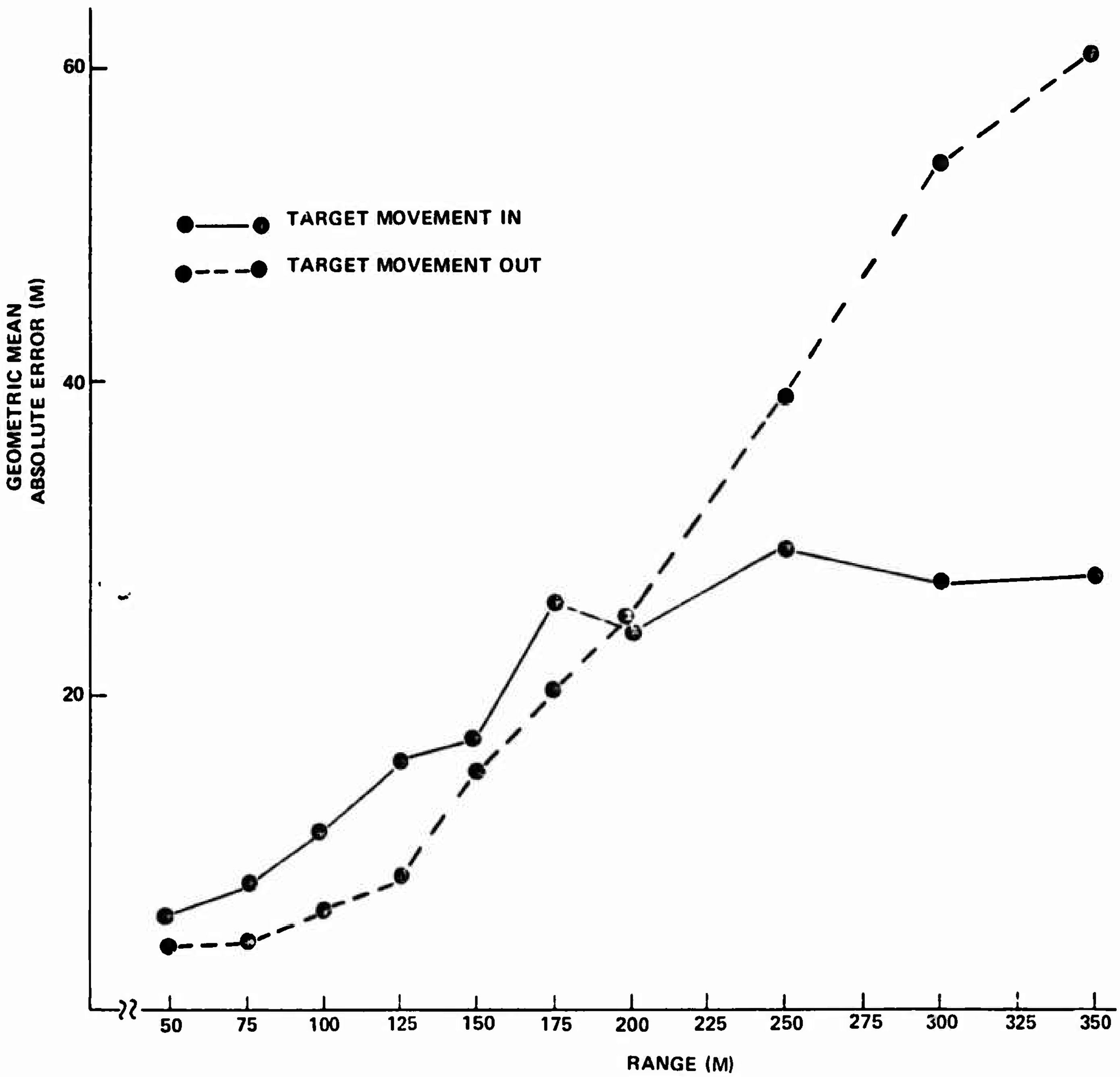


FIGURE 8. GEOMETRIC MEAN ABSOLUTE ERROR IN METERS FOR ALL INCOMING AND ALL OUTBOUND TARGETS IN EXPERIMENT 3.

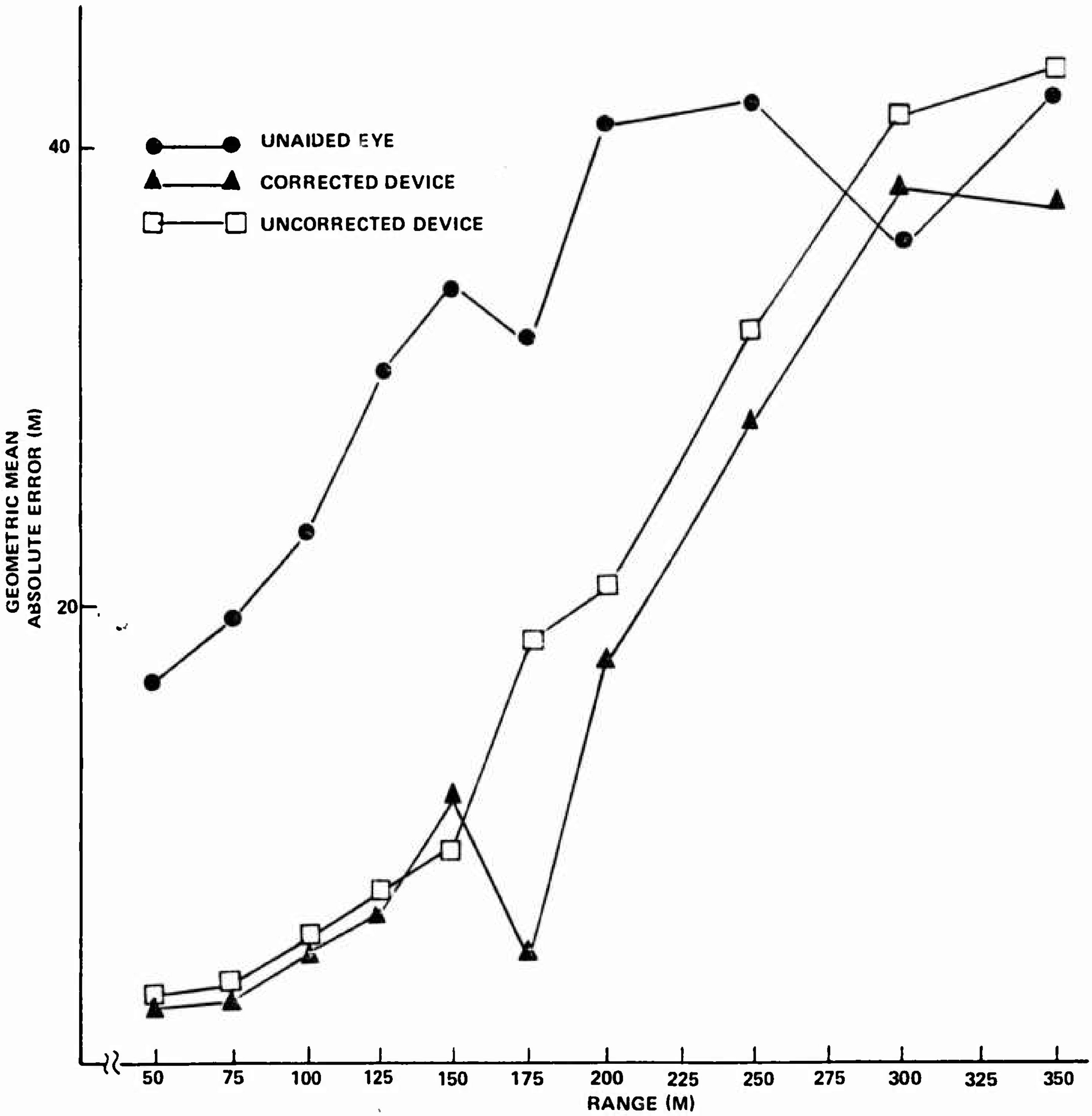


FIGURE 9. GEOMETRIC MEAN ABSOLUTE ERROR IN METERS FOR TARGETS VIEWED WITH THE UNAIDED EYE AND CORRECTED AND UNCORRECTED DEVICES IN EXPERIMENT 3.

experiment. Figure 6 indicates this analysis is practical only for ranges between 50 and 150 meters. The percentages of estimates within 5 m of the intended range (i.e., the hit radius of most M203 grenades) are shown in Table 4. The poor performance of observers using the unaided eye is striking. The devices, in comparison, offer uniformly better performance which starts to approach that of the eye at 150 m. The in-out difference is also apparent and results in a slight overall advantage for the corrected device.

Table 4

Percentage of Estimates Within
5 Meters of Actual Range

	Unaided Eye		Corrected Device		Uncorrected Device	
Range	In	Out	In	Out	In	Out
50	6.3	18.9	69.3	81.9	69.3	81.9
75	12.6	18.9	44.1	62.9	25.2	75.6
100	6.3	25.2	37.8	50.3	31.5	63.0
125	6.3	18.9	25.2	37.8	6.3	18.9
150	0.0	12.5	18.9	18.9	31.4	18.9

Variable Error. An additional perspective on the differences in range estimation is to assess how consistent each observer's estimates were under the various methods of viewing. To carry out this analysis, the standard deviation of an observer's in and out estimates were computed for each method of viewing at each range. The standard deviations were computed for the signed errors of estimation; that is, the raw data were the number of meters short (a negative value) or beyond (a positive value) the intended range the observer positioned the target. These standard deviations were in turn transformed to logarithms and a 3 x 10 repeated measures analysis of variance was performed which incorporated the specific contrasts used earlier. The analysis is summarized in Table 5. Geometric means of the standard deviations are shown in Figure 10.

These data provide conclusions supportive of earlier findings. Compared to device estimates, estimates with the eye were less consistent; that is, they showed more variability between the in-out target movement condition than did estimates made with the devices, $F(1,15) = 15.45$, $p = .0013$. The devices, although providing significantly better ranging performance, were not significantly different from one another, $F(1,15) = 2.98$, $p > .05$. All three viewing conditions resulted in greater intraindividual variability as range increased, but at rates that were the same as shown in the significant linear

Table 5

Summary of Analysis of Variance
of Variable Error of Range Estimates

Source	Sum of Squares	df	Mean Square	F	Probability
M (Method of Viewing)	15791.30000	2	7895.64000	12.73	0.0001
Error	18606.73800	30	620.22461		
ED (Eye-Devices Comparison)	14987.30000	1	14987.30000	15.45	0.0013
Error	14554.77400	15	970.31823		
CU (Corrected-Uncorrected Device Comparison)	803.99100	1	803.99100	2.98	0.1050
Error	4051.69490	15	270.13099		
R (Range)	37857.20000	9	4206.35000	22.59	0.0000
Error	25140.17900	135	186.22355		
L (Linear Trend)	37308.00000	1	37308.00000	30.78	0.0001
Error	18183.19600	15	1212.21310		
Q (Quadratic Trend)	392.90000	1	392.90000	1.92	0.1865
Error	3075.10430	15	205.00695		
M x R	1040.95000	18	57.83040	0.50	0.9564
Error	31131.14000	270	115.30052		
ED x L	149.84100	1	149.84100	0.14	0.7090
Error	15535.24700	15	1035.68310		
ED x Q	119.07400	1	119.07400	0.54	0.4743
Error	3316.02130	15	221.06809		
CU x L	99.00540	1	99.00540	0.34	0.5688
Error	4375.86010	15	291.72401		
CU x Q	192.39300	1	192.39300	3.01	0.1030
Error	957.57452	15	63.83830		

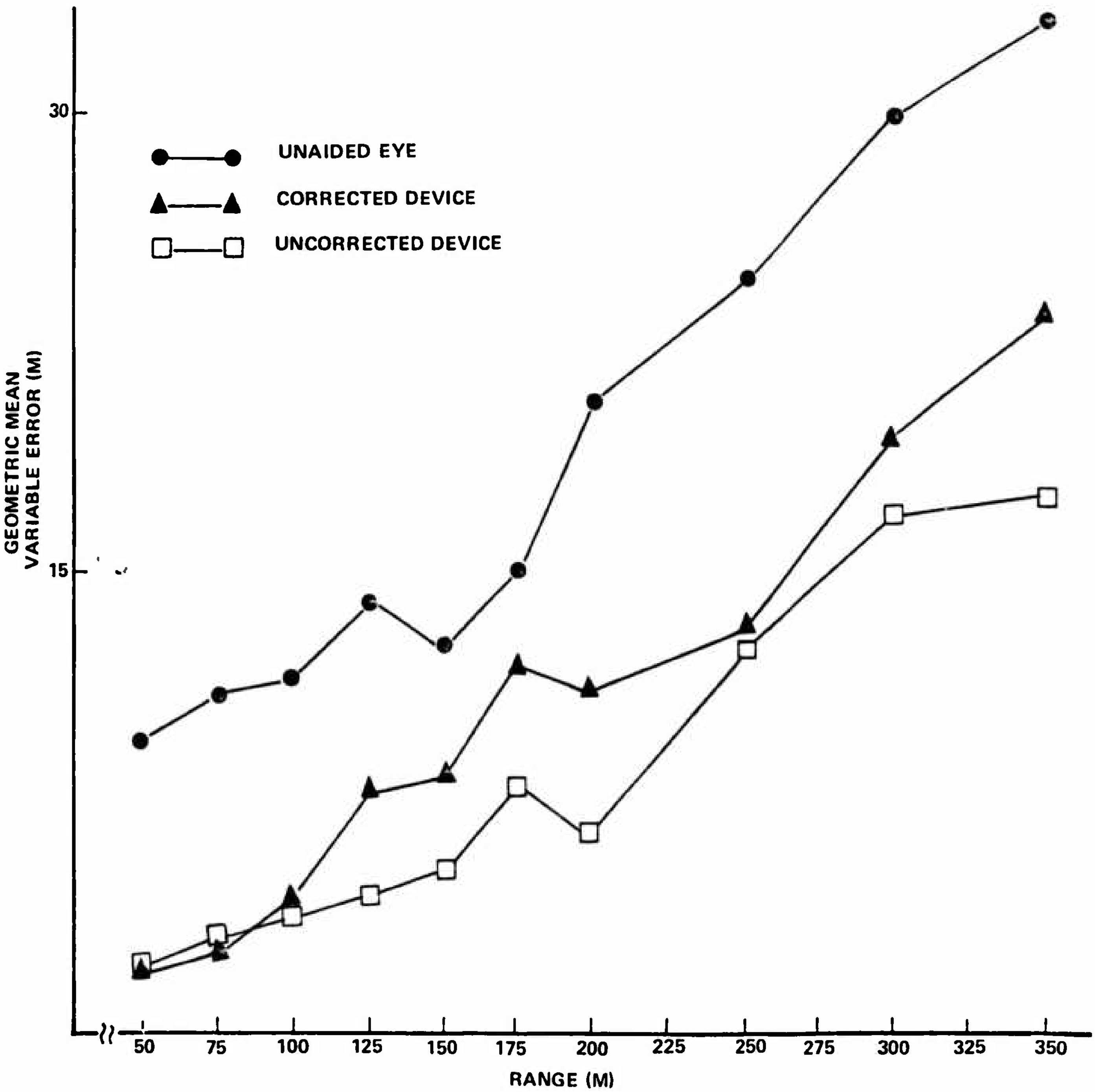


FIGURE 10. GEOMETRIC MEAN VARIABLE ERROR IN METERS FOR TARGETS VIEWED WITH THE UNAIDED EYE AND CORRECTED AND UNCORRECTED DEVICES IN EXPERIMENT 3.

trend, $\underline{F}(1,15) = 30.78$, $\underline{p} = .0001$, but nonsignificant Method of Viewing x Range interaction, $\underline{F} < 1$.

Discussion

This experiment was designed to test the original range estimation device developed on the basis of simple trigonometric relationships against a similar device corrected for systematic perceptual biases found in the original. Both devices were tested by the same soldiers and comparisons were made to their range estimates with the naked eye. The expectation was that use of the devices would result in an improvement in range estimates, and that the corrected device would prove to be more accurate.

Using the naked eye, soldiers in this experiment showed the same tendency as those in Experiment 1 to overestimate distance to all ranges beyond 50 m. The magnitude of overestimation found was somewhat greater than in Experiment 1, but in general showed a remarkably similar functional relationship between judged distance and actual distance. If this overestimation tendency is interpreted in the context of M203 grenade launcher performance, beyond 150 m the percentage of range estimates that would have resulted in first round hits is close to zero. Between 50 and 150 m, as Table 4 shows, less than 1 estimate in 5 was acceptable for point target accuracy.

This bias towards overestimating range, a perceptual process sometimes referred to as overconstancy, is less pronounced for the unaided eye, especially beyond 175 m, when the target sequence is away from the observer. This result is understandable given that observers had a real zero point from which to judge distance (i.e., the target stood immediately before him at the beginning of the "out" estimation sequence). The various methods taught soldiers to estimate range use the soldier's position as the reference point from which he lays out fixed-intervals from himself to the target location.

A corresponding reference point was not available in flat, open terrain when the target's initial position was well beyond 350 m. One should recognize that the "unaided eye in" data represent range estimation capability for threat targets under combat conditons. That is, enemy targets will be moving predominately from a distant point toward the observer. In the absence of any knowledge on the soldier's part of the distances from his location to points in his sector of fire, the expectation is that serious overestimations of range will occur for most in-bound man-sized targets.

It was this observation, originating from Experiment 1, which lead to the development of the ranging device. The original device was constructed with hole sizes corresponding to man-size images. On the basis of pilot testing results, adjustments to these hole sizes were calculated for some of the ranges, and a second device constructed. This experiment tested both devices under identical conditions and found no compelling reason to favor one device over the other. In terms of the magnitude of errors of estimation (absolute error) or the intrasubject variability of estimates, no significant differences were found between the capabilities of the devices.

The corrected device appears in Figure 6 to offer some advantage compared to the uncorrected device, in that range estimates seem to be closer to the correct values in the ranges beyond 200 m. But, the direction of target movement is the more potent source of influence for these longer range estimates. As targets retreated from the observer, underestimation of range became more pronounced. The movement of targets towards the observer yielded less underestimation. This latter condition more closely approximates a critical combat situation, but the overlap of the individual range estimates for both devices is such that a clear statistical distinction between the two devices is not possible. What is clear, however, is that for in-bound targets, either of the devices offers a distinct advantage in producing more accurate, although not perfect, range estimates than does the unaided eye.

That the direction of target movement relative to the observer should play a role in the use of the devices was not unexpected. Jenkins (1959) noted that errors in size matching differed in magnitude depending on whether the variable stimulus was increasing or decreasing in size. Programmatic research of aerial target range estimation by McCluskey, Wright and Frederickson (1968, Control Group, Experiment 1) revealed a marked tendency of subjects to overestimate a criterion range of 350 m on an order of magnitude of 100 percent for incoming and about 30 percent for outgoing aircraft. These in-out differences could be trained out with the use of ranging aids. The combination of scaled target training and the use of a stadiametric ranging aid (the front sight guards of a M14 rifle) resulted in a general shift to underestimation. Of particular interest, though, was that estimates to incoming aircraft at 350 m became more accurate than for outgoing aircraft at the same distance.

McCluskey (1971) subsequently replicated this finding at 1500 m using a single post at 30 in. from the eye as the ranging aid. The width of the post was equal to the apparent wingspan of an aircraft when viewed at 1500 m. Ton (1972) obtained greater underestimation of outgoing (diminishing image) "aircraft" when he simulated McClusky's (1971) experimental procedure on an oscilloscope. However, greater underestimation linked to diminishing images has not been universally found. Baldwin (1973) provided observers a task in which they matched the size of a horizontal bar continuously varying in width (cf. the wingspan of an incoming or outgoing aircraft) to a constant width bar located .75 m from the observer; he found a reversal in ascending-descending errors. As the variable bar width increased (simulating incoming aircraft) observers erred in stopping the variable too soon, which is equivalent to overestimation of range. Descending trials tended to be quite accurate, corresponding to accurate estimates of outgoing aircraft.

The predominant finding that receding images are seen as reaching criterion range or image size too soon was first found in the context of anti-aircraft gunnery. The present land-based range estimation device development found the same underestimation for retreating targets. The most plausible explanation for this finding may be linked to why all device estimates were underestimates. Three explanations can be suggested. One possibility is that the fitting of the images was influenced by monocular viewing of a dimensionless, homogeneous background, particularly through the smaller holes. Research has shown that the ability to estimate distance in such a "Ganzfeld" is severely limited (Murch, 1973). Observers are not able to estimate accurately distances between themselves and an image projected into an otherwise featureless field of view. In our experiment, looking down the runway through a small hole, using one eye, and fixating on the target duplicates major features of the Ganzfeld environment. However, the observers in this experiment were not asked to estimate distances from themselves to the target standing in a featureless surround. Their task was to fit the image to the size of the hole. Since this critical aspect of the Ganzfeld procedure was not duplicated here, an explanation of the underestimation on the basis of the Ganzfeld phenomenona is not helpful.

A second possible explanation is the nearsightedness which results when an observer looks through a small aperture, such as in optical devices. Under this condition of monocular viewing, the requirement for the eye to accommodate is markedly reduced and the eye becomes focused for points closer than objects of interest in the field of view (Leibowitz & Owens, 1975). Objects are brought into focus by adjusting the optical instrument with positive diopter corrections. While this experiment did not use an optical instrument, the nearsightedness could have been produced by viewing through the small holes. Rather than having an optical adjustment to focus the image, the soldiers could move the target to a point of clearer image. The direction of movement would be toward the observer, closer than if the judgments were made without the device. The resulting range estimates would be underestimations.

This explanation is not supportable for the same reason the Ganzfeld explanation was discounted. Again, the reason is methodological. The observer's task was not to produce the sharpest possible overall image, but rather to fit the borders of image and hole together. It should be noted that the Ganzfeld procedure is also regarded as producing nearsightedness (myopia) as does the act of peering with one eye through a small hole (sometimes referred to as instrument myopia). Both Ganzfeld myopia and instrument myopia are classified together as anomolous myopias (Leibowitz & Owens, 1975), but have been discussed separately here to explore various aspects of our experimental procedure.

The most plausible explanation, which also can account for the in-out target movement differences, has to do with the the property of light passing through small apertures: the pattern of light as it emerges from the opening is made up of a central area of a bright image surrounded by a less intense and less distinct shadow region. This phenonenon is referred to as diffraction (Ogle, 1968). The alteration in the appearance of the target's outline passing through the small aperture may have affected observers in this experiment. Their task was to fit the top and bottom edges of the target to the edge of the aperture. Since the image was being diffracted, a distinct target edge was not visible to the observer; the observer then had to approximate a fit of the image to the hole. His judgmental bias was to fit the brighter, more distinct central area to the edge of the aperture, which meant increasing the size of the central portion of the image. This was accomplished by moving the target closer.

Diffraction explains the general underestimation evident with the devices. The differences between underestimation as a function of direction of target movement may be explained by different decision rules employed by the observer. As the target moved out, estimates began with large holes which resulted in minimal diffraction. The observer, therefore, began with clearly bordered target images easily fit to the sharp edged holes. As the target image diminished and smaller holes were used, diffraction increased but the observers continued to fit to the more distinct central image. This fitting rule stopped the target short of the correct distance.

Incoming targets were fit to the smallest holes first; but it is these smallest holes which produce the most diffraction (Ogle, 1968). The observers adopted a judgemental set of fitting the less distinct edge of a difficult-to-see image to the aperture. The visual effect of diffraction was minimized by doing so, and thus the image size more closely corresponded to the geometrically determined hole size for the range being estimated. The point at which target movement was halted was closer to the intended range as a consequence of this decision rule.

In summary, a major finding of this experiment is that experienced soldiers show the same error tendencies as trainees in making estimations of distance. Soldiers can discriminate distance in a systematic fashion, but they do so with a margin of error which becomes greater as distance increases. The two versions of the ranging device offer a simple solution to this problem, with a minimum of bias for in-bound targets. This bias points means that rules for properly using the device are critical to its effectiveness.

GENERAL DISCUSSION AND CONCLUSIONS

Ranging Device Effectiveness

The informal observations made of the range estimation abilities of trainees were confirmed with the more formalized procedures of Experiments 1 and 3. Both newly trained (Experiment 1) and seasoned soldiers (Experiment 3) make overestimations of range as the distance between themselves and targets increases. The data obtained in these experiments pointed to very low first round hit probabilities had these soldiers fired the M203 based on these estimates. Although grenadiers are taught that fire can be adjusted on the basis of "sensings" from preceeding rounds, the results of this research point to the potential for considerable improvement in accuracy of first rounds and perhaps subsequent rounds as well.

The greatest improvement in range estimation judgments when using the ranging aid was for those targets placed beyond 150 m. At less than 150 m the average judgment using the ranging aid appeared sufficiently close to unaided eye estimates to be of little practical importance. But the judgments with the devices were shown to be more consistent than their unaided eye counterparts. Over a large number of estimates, then, device-based estimates would probably cluster closer to the intended range than naked eye estimates. This would argue for using the device for estimates across the entire 50 to 350 m range of the M203 grenade launcher. Other advantages of the ranging device are:

- the M203 quadrant sight is calibrated for the ranges 50 to 400 m in 25 m increments. The ranging device incorporates all but five of those ranges;

- optical distortion and reflective glare from viewing the target through a clear plastic stadiametric system are eliminated;

- the device was designed to substitute for the leaf sight which is redundant with and less accurate than the quadrant sight and whose use is not emphasized in the M203 program of instruction;

- the device does not require the target be a man, but any six foot object (e.g., hood height on a truck) which can be oriented vertically, horizontally, or obliquely;

- the device is effective, simple, rugged, and low cost.

Stadiametric Principles

Another aim of this research was to investigate an alternative to stadia lines embedded in plastic or etched into high quality optical instruments. The use of keen edged holes appears to have eliminated the problem of line width of the markings which form the stadiametric system. But the apertures themselves introduce diffraction of the image. Thus, the problem of fitting the apparent size of the target to a standard shifts from error originating with the standard to errors arising from the target image. Apparently, then, stadiametric systems, which require the target image outline to be matched to an outline or form of the standard, always can be expected to produce errors in fitting the image and the standard.

Giordano (1976) estimated that the magnitude of underestimation of range with the M72 LAW sight was from 1 to 5 percent between 100 and 350 m when viewing head-on tank targets. This underestimation was due to the soldiers fitting a tank image to the edge of the stadia lines whereas the sight designer used the midline of the stadia line thickness as the intended region of correct fit. When viewing man-sized targets using the present M203 ranging device, soldiers showed a 1 to 8.5 percent underestimation of range for incoming targets. Giordano (1976) did not investigate the influence of direction of target movement, but did show that a design error of eye-to-sight distance of the M72 LAW sight resulted in range underestimation errors of about 5 percent. This latter source of error was not a contributing source of error for the ranging aid investigated here.

Training Implications

Despite the preliminary finding that a few trials of training the "sight picture" of the target image in the hole had negligible effect, the interpretation that diffraction resulted in the underestimations and in-out target movement differences implies thorough training may lead to more accurate estimates. The fact that the image goes through qualitative changes as hole size changes was reported by the observers in Experiment 2. Since judgments are involved as to when the image fits the hole, a series of exercises could provide fitting rules emphasizing these qualitative changes. These exercises could be done on full scale ranges, but evidence already exists that reduced scale training is effective in training stadiametric range finding (McCluskey, 1971; McCluskey, Wright, & Frederickson, 1968). The fitting error observed for the M203 ranging device might very well be removed by training soldiers to use the proper procedures.

Training in the tactical use of the device could cover the following points:

- the device is best used in a defensive position to identify distances to features in the terrain;

- the device will be of different value to different firers. Some soldiers can estimate range surprisingly well. The soldier less capable of making naked eye estimates can use the device more often. Training could therefore identify who needs to use the device and under what conditions;

- in conjunction with using the device for range estimates, techniques of hold-off and rapid reload need to be emphasized to adjust fire and quickly launch another round. Neither technique currently is emphasized during initial entry training, although ranging errors are likely to limit greatly the probability of first-round hits.

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APPENDIX A

RANGING DEVICE HOLE DIAMETERS

Calculated Hole Diameters and Actual Hole Diameters for
Original (Uncorrected) and Adjusted (Corrected) Ranging Devices

	Original Device			Adjusted Device		
		Micrometer Measurements			Micrometer Measurements	
Range (m)	Calculated Diameter	First Gunsmith	Second Gunsmith	Calculated Diameter	First Gunsmith	Second Gunsmith
50	.634	.637	.637	.675	.696	.698
75	.423	.428	.429	.435	.439	.444
100	.317	.314	.315	.319	.324	.325
125	.254	.250	.250	.250	.251	.251
150	.211	.210	.210	.206	.205	.209
175	.181	.179	.179	.174	.172	.172
200	.159	.162	.162	.151	.143	.143
250	.127	.129	.127	.118	.110	.110
300	.106	.103	.105	.097	.089	.089
350	.091	.087	.088	.082	.071	.071

Note. All measurements except range are in inches.